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# A RAND NOTE

## The Development of the Advanced Medium-Range Air-to-Air Missile: A Case Study of Risk and Reward in Weapon System Acquisition

Kenneth R. Mayer



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Prepared for the
United States Air Force

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## PREFACE

This Note presents one of seven case studies of the development of major weapons systems carried out as part of the Project AIR FORCE study "Managing Risks in Weapon Systems Development Programs." The larger study addresses the manner in which government policies and practices shape the management of risk during the design and development of major weapons systems. The study is intended primarily for higher-level Air Force, Department of Defense (DoD), and congressional personnel who create the environment and policies governing the acquisition process. However, the overall study and the supporting case studies should also be useful to policy analysts concerned with the management of large-scale research and development programs, particularly in the DoD.

The seven weapons systems that are the subjects of the case studies were chosen to represent a variety of systems types, sizes, and technological difficulties. The case studies are limited in scope, focusing primarily on identifying the risks in the programs, the degree to which those risks were anticipated, and the steps that were taken to deal with those risks. The seven case studies are documented in the following Notes:

- Susan J. Bodilly, *Case Study of Risk Management in the USAF B-1B Bomber Program*, N-3616-AF, 1993.
- Susan J. Bodilly, *Case Study of Risk Management in the USAF LANTIRN Program*, N-3617-AF, 1993.
- F. Camm, *The Development of the F100-PW-220 and F110-GE-100 Engines: A Case Study of Risk Assessment and Risk Management*, N-3618-AF, forthcoming.
- F. Camm, *The F-16 Multinational Staged Improvement Program: A Case Study of Risk Assessment and Risk Management*, N-3619-AF, forthcoming.

- Kenneth R. Mayer, *The Development of the Advanced Medium-Range Air-to-Air Missile: A Case Study of Risk and Reward in Weapon System Acquisition*, N-3620-AF, 1993.
- T. J. Webb, *Risk Management During the Development of the Global Positioning System Block I Satellite*, N-3621-AF, forthcoming.
- T. J. Webb, *Risk Management in Preparing for Development of the Joint Surveillance Target Attack Radar System (Joint STARS)*, N-3622-AF, forthcoming.

The Air Force sponsor for these studies is the Deputy Assistant Secretary of the Air Force (Contracting) (SAF/AQC). The work was conducted in the Resource Management Program of Project AIR FORCE.

## SUMMARY

This Note is a case study of the Advanced Medium-Range Air-to-Air Missile (AMRAAM) program, part of a study of risk and reward in weapons acquisition programs. Unlike with the traditional case study, or "lessons learned" approach to acquisition analysis, the intent is not to isolate specific factors, internal to a given program, that are examples of good or bad management technique. Rather, the intent is to take a broader view of the acquisition process and to seek to understand the connection between the perceived *risks* involved in the development of acquisition programs and the *rewards* that can be obtained when the system works smoothly. Obviously, both of these terms represent fuzzy concepts and mean different things to each of the many actors in the acquisition process (contractors, system program offices [SPOs] in the Air Force, service commands, OSD, Congress). What we seek to understand, however, is how SPOs and contractors in particular attempt to manage risk in their programs, either through specific steps and procedures or broader philosophies of how to conduct programs, and how those activities relate to the potential rewards.

The general approach taken in this case study is to consider acquisition programs as part of a "political" process involving decisions about resource allocation and how the perceptions and goals of the different organizations that contribute to the process affect SPO and contractor management. As such, it is important to study not just what happens within a particular SPO, but the broader questions of the types and levels of external demands imposed on a program and how outsiders view program events.

Few acquisition programs have attracted as much attention and controversy as AMRAAM. The program's problems included substantial cost growth; major schedule slips; several major redesign efforts, one during validation, another after production

was originally scheduled to begin (and months before the initial estimated IOC); regular congressional attempts to curtail or cancel the program; and stringent externally imposed testing requirements. For most of the 1980s, the program seemed to be "out of control."

The troubled AMRAAM program has two particularly interesting characteristics. First, despite the program's difficulties, it now appears that *technologically* the missile is a success--it is likely to fulfill the original requirements and do what the Air Force wanted;[1] even critics admit that the system will work (though they may dispute the need for the missile or object to its cost). Second, in managing the missile, the Air Force made an attempt (or gave the *appearance* of making an attempt) to do everything "right" in terms of adherence to acquisition policies designed to minimize the chances of serious problems developing: thorough risk assessment and exploration of alternatives, consultation with end users about requirements, giving contractors maximum design flexibility, extensive prototyping, and competition. And still, near-fatal problems arose.

The most important theme to draw from this case is the importance of managing expectations. The chief cause of AMRAAM's woes is that managers vastly oversold the program in terms of cost and schedule. The early cost estimates were, according to at least one program official, made for advocacy reasons. The early compressed schedule (from over 90 months to 70) was designed to respond to congressional pressure to shorten the acquisition cycle and provide AMRAAM capability to F-16s in Europe. As a result of the shortened schedule, important design tasks were slipped from DEM/VAL into FSD to allow the program to make the early milestones on time. When the system encountered serious technical problems

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[1]The only deviations from the original JSOR specifications are slight reductions in F-Pole (a measure of the relative distance between the launch and target aircraft) and launch-to-eject time. The reduction in the missile's range resulted from a slight weight increase and a quarter-inch increase in missile diameter along the GCS section of the missile, which increased drag.

in 1983-1984, the gap grew between what had been promised and what was being achieved. OSD and congressional oversight increased, and external authorities (particularly Congress) became "hypervigilant," focusing on development and testing problems--common to any program--to the point where even the most minor difficulties (failure of a single test, for example) put the program at risk of cancellation. Once this point had been reached, SPO management became heavily involved in defending the program as well as in managing it.

This study proceeds as follows: Section 1 sets out the overall approach of thinking about risk in an institutionally dynamic setting. Section 2 is a history of AMRAAM development and focuses on the early stages of the program, particularly 1978 to 1985. The history relies primarily on publicly available documents (GAO reports, trade press information), internal SPO documents, and interviews with present and former SPO, contractor, and OSD personnel. Section 3 is an attempt to place the AMRAAM program in the context of the discussion of risk in Section 1. Most interviews were conducted on a "not for attribution" basis; the convention followed throughout this study is that remarks enclosed within quotation marks that are not cited are from the interviews.

## ACKNOWLEDGMENTS

This report would not have been possible without the assistance and cooperation of many people throughout the Air Force and in the defense industry. The author would like to thank the past and present members of the AMRAAM program office, especially Colonel Riley Shelnutt; the staff of the Historical Office of the Air Force Systems Command and Hughes Aircraft Company (Canoga Park and Tucson) for consenting to interviews and making available important documents. Within RAND, the author benefitted from the advice of Arnold Levine, who reviewed a draft of the report.

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## TABLES

# ABBREVIATIONS

| Abbreviation | Definition |
|---|---|
| AFOTEC | Air Force Operational Testing and Evaluation Center |
| AFSC | Air Force Systems Command |
| AIMVAL/ACEVAL | Air Intercept Missile Evaluation/Air Combat Evaluation |
| AMRAAM | Advanced Medium-Range Air-to-Air Missile |
| AMS | Advanced Monopulse Seeker |
| APREP | AMRAAM Producibility Enhancement Program |
| BVR | Beyond Visual Range |
| CDT&E | Contractor Development Testing and Evaluation |
| DAB | Defense Acquisition Board |
| DCP | Development Concept Paper |
| DEM/VAL | Demonstration and Validation |
| DSARC | Defense Systems Acquisition Review Council |
| ECCM | Electronic Counter-Countermeasures |
| ECM | Electronic Countermeasures |
| FSD | Full-Scale Development |
| GAO | General Accounting Office |
| GCS | Guidance and Control System |
| GM | General Motors Corporation |
| GRC | General Research Corporation |
| HAC | Hughes Aircraft Company |
| IOC | Initial Operating Capability |
| IR&D | Independent Research and Development |
| JRMB | Joint Resources Management Board |
| JSOR | Joint Strategic Operational Requirements |
| JSPO | Joint Systems Program Office |
| LSIC | Large-Scale Integrated Circuit |
| OSD | Office of the Secretary of Defense |
| OT&E | Operational Testing and Evaluation |
| $P^3I$ | Pre-Planned Product Improvement |
| SIRCS | Shipboard Intermediate Range Combat System |

| | |
|---|---|
| SPO | System Program Office |
| SST | Solid-State Transmitter |
| TEMP | Testing and Evaluation Master Plan |
| TWT | Traveling Wave Tube |
| VHSIC | Very-High-Speed Integrated Circuits |

# 1. RISK AND REWARD IN ACQUISITION

## DEFINING RISK

The general conception of risk in this case study is taken from Camm,[2] who argues that risk exists when there is a significant probability of some adverse event. Although engineers will typically define risk in terms of the probability of not meeting a particular technical goal, an "adverse event" may be any of a number of things:[3]

- A technical failure during testing, indicating that the system design is flawed;
- Realization that the system does not perform as expected in terms o technical characteristics, reliability, etc.;
- Difficulties in managing the transition from development to production (inability to produce the system in quantity);
- Schedule delays; or
- Significant cost increase.

Note that the last two items on this list will generally result from the first three types of adverse events.

A broader conception of risk in acquisition programs recognizes that what matters, in terms of the impact on particular programs, is not the occurrence of adverse events but what they mean to the various constituencies involved in the program. Peck and Scherer utilized this type of definition when they

[2]Frank Camm, *The Development of the F-100-PW-220 and F-110-GE-100 Engines: A Case Study of Risk Assessment and Risk Management*, N-3618-AF, forthcoming; Frank Camm, The F-16 Multinational Staged Improvement Program: *A Case Study of Risk Assessment and Risk Management*, N-3619-AF, forthcoming.

[3]This list is not meant to be exhaustive but rather illustrative.

characterized risk as "the level of consequences of a wrong prediction."[4] The utility of this approach is that it recognizes that the same type of event, in two separate programs, may have very different consequences, depending on how the event is interpreted. A failure during testing may have a range of effects, from having little impact on a program to calls for cancellation (a recurring theme during AMRAAM's [Advanced Medium-Range Air-to-Air Missile] development). How that event is interpreted may depend on (1) plans within system program offices (SPOs) to minimize the impact of the adverse event through contingency plans for solving the problem (existence of alternative designs, workarounds, etc.), (2) willingness to make tradeoffs by giving up a capability that is beyond the state of the art as revealed by the failure, and (3) the expectations of external actors about the seriousness of the failure. One major task in categorizing risk, therefore, is identifying the intervening factors that shape the interpretation of adverse events.

To make this argument about the *interpretation* of risk being a crucial component, it is necessary to make three assumptions about how organizations view risk. First, the interpretation of an adverse event is conditioned by expectations of what the result would be. If engineers, command authorities, external oversight organizations, etc., anticipate the difficulty in demonstrating a particular technical advance--if they agree that a particular technical goal will be hard to achieve--they will view a failure in this area in a less negative light than if the expectation was that success would be easily achieved. A simpler way of putting this is that unexpected failures are worse than anticipated ones.

This point places program managers in a difficult position because it is generally accepted that it is impossible to

[4]Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process: An Economic Analysis* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1962), p. 19.

eliminate all surprises from advanced development programs: no amount of planning for anticipated problems can eliminate the risk of "unknown unknowns," which are by definition impossible to identify. No treatment of the development and acquisition process suggests that it is possible to get everything right the first time. This characteristic of development programs is not, apparently, well understood by external authorities, especially Congress: problems *always* develop during design and testing. Moreover, we should probably be suspicious of any new development program that *does* get everything right, because that probably suggests that the system does not push the state of the art far enough.[5] Such a program would probably not be approved anyway; competitive pressures within the services prod advocates of development programs to be optimistic about what their system can achieve.

The second assumption about how adverse events are interpreted is that the greater the shortfall between what has been promised and what is being achieved (i.e., the bigger the level of surprise), the more adverse the interpretation given to the event that brought the shortfall to light. Again, this is a dilemma for program managers. Any program faces competition for limited resources, and advocates have strong incentives to portray their alternative in a positive light: optimistic estimates of performance, schedule, or cost can generate institutional support within the service and also make OSD and congressional approval more forthcoming.[6] Overselling a program at the beginning, however, can lead to serious problems later on, as the failures and shortfalls that inevitably occur during development--either in the form of performance problems, cost increases, or schedule

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[5]Any manager could promise perfection, and probably deliver, by simply proposing a system that includes no improvements over existing technologies.

[6]This is not a new problem. Peck and Scherer noted over 20 years ago the tendency for contractors to be optimistic about what they will be able to achieve and that the "government literally compels contractors to submit proposals which it knows are unrealistically optimistic." See Peck and Scherer, p. 412.

delays--can lead to serious criticism (and the highest risk, that of program cancellation) and a heightened degree of external attention, oversight, and direction. The steps often required to get programs started, and thus minimize the short-term risk of not getting approval, can also increase long-term risk by increasing the probability that failures will be interpreted in a more negative light. Program advocates and managers must therefore strike a balance between being *too* optimistic and not promising enough to get the program started; they must manage the expectations of those organizations responsible for oversight so that when adverse events occur, those organizations will view them in the proper context.

The third assumption about interpretation of adverse events is that the greater the degree of program visibility, the greater the "risk" inherent in any single event. Consider one extreme, an adverse event that has zero visibility outside the SPO or contractor; this can occur because the event is a minor one with little impact on the program or because the program does not generate much attention outside the SPO. In this case, assuming that the failure can be corrected, managers have the flexibility to fix, or work around, the problem without external actors even knowing that a problem exists. At the other end of the spectrum, adverse events in highly visible programs will most likely generate substantial attention and criticism. A program's visibility among actors external to the program (chiefly service commands, OSD, and Congress), especially Congress, tends to be higher when it is already controversial. That controversy may arise because of the nature of the program itself--as one example, strategic programs generate more attention on Capitol Hill than more mundane conventional programs--or because of perceptions that a program is already experiencing some type of difficulty; adverse events tend to attract attention.

Once external actors become involved, they can constrain management flexibility within the SPO and often make demands on the program that, in the eyes of SPO personnel, interfere with

effective management. In the case of AMRAAM, Congress in 1985 insisted as a matter of law that the system meet *all* of the original performance specifications.[7] This eliminated all flexibility within the SPO to engage in any sort of cost-performance tradeoffs. Moreover, SPO personnel argue that the AMRAAM testing requirements imposed by Congress were unrealistic in that they required "perfection" prior to production approval. This subject is discussed in more detail in Section 2 of this Note.

**MANAGING RISK**

The different organizations involved in defense acquisition accept a certain level of risk in development programs, because they hope to achieve some sort of reward. To understand this side of the equation, it is necessary to specify the goals of the different organizations involved in the acquisition process and how their respective positions determine how they evaluate risk. This is a difficult enterprise, because it is not possible to speak of a unitary position within a particular organization: different actors, even within an organization, will have different perceptions of what they define as an "adverse event." As but one example, one assumed goal of SPOs is to move a system from development to production and achieve IOC as quickly as possible,[8] even to the point of fielding a system that fails somewhat short of the original performance or reliability requirements (perhaps with the expectation that marginal improvements can be made after the system is in the inventory). The testing community in the Air Force (and the independent testing community within OSD), however,

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[7]Section 210 of the Fiscal Year (FY) 1986 Department of Defense Authorization Act requires the Secretary of Defense to certify that "system performance has not been degraded from the original development specification (DS 32050-00, as amended by the draft Development Concept Paper [DCP] of June 14, 1985)."

[8]Of course, it is plausible that different SPOs will have different opinions on this issue, with some preferring to achieve performance, even if it means accepting a schedule delay.

may be more concerned about insuring that those requirements are met, even if it means delaying production.

As a starting point, consider the basic goals of the acquisition organizations and assume for the moment that the organizations are unitary and that the goals of the suborganizations are the same as the goals of the entire organization. This assumption will be relaxed momentarily. At a minimum, the basic goal of a weapons development program is to produce an operationally capable and affordable system that meets performance requirements.[9] Yet, we return to the point that acquisition programs cannot be understood in isolation but must be considered as part of a broader political process involving competing organizations and constituencies. Consider the following explication of organizational goals:[10]

- Air Force
  - Operationally capable systems that allow the service to fulfill its role of defeating enemy forces;
  - Protection of budgets and missions against cuts and reallocations; and
  - Credibility with external actors, principally OSD and Congress, and influence within these organizations with respect to policy outcomes that affect the Air Force.
- System Program Offices (subunit)
  - Fielding operationally capable systems that meet mission, schedule, and cost goals;
  - Preserving management autonomy and freedom from external constraints;

[9] Of course, "operationally capable," "affordable," and "performance requirements" mean different things to different constituencies.

[10] Note that this list is highly subjective and certainly not intended to be comprehensive. Nevertheless, it does highlight some reasonable expectations of the general nature of what the groups hope to accomplish.

  - Credibility with higher command authorities within the Air Force; and
  - Career goals of officers and civilian personnel within the organization.
- OSD
  - Ensuring that service activities are consistent with national security policy as articulated by the national command authorities;
  - Management autonomy; and
  - Protection of budgets from external criticism and cuts (largely by Congress).
- Contractors
  - Return on investment, cash flow, and profit margins, both short and long term;
  - Protection against financial losses;
  - Competitive position in the marketplace, future business opportunities for developing and building weapons systems;
  - Maintaining a competitive technology base; and
  - Prestige and public image.
- Congress
  - Protection of constituent interests, re-election considerations;
  - Cost-effectiveness concerns; and
  - Influence over military policy and resource allocation within the Department of Defense.

We can make a few observations about organizational goals without relying too heavily on the specifics of this list. First, *it is not possible to achieve all goals simultaneously*. Indeed, organizations should not even attempt to do so; they must establish priorities and make tradeoffs. A few simple examples illustrate the point. Even among the basic parameters of a given program--cost, performance, schedule--SPOs and contractors must decide which is most important: maximizing performance requires

accepting longer schedules and higher costs and means that program managers must accept a higher probability that technical goals will not be achieved. This poses a problem for management, because it places in conflict the obvious goals of fielding a capable system and doing so quickly. Putting in enough schedule slack to allow for every contingency means that development cycles are unacceptably long (and may jeopardize support in OSD and Congress), and rushing systems into the field quickly usually implies that initial production units will not meet performance standards.

Contractors, in particular, face stark choices when deciding how to position themselves with respect to a particular program. While they must bid aggressively in terms of performance and cost to increase their chances of winning a contract, especially in a competitive situation, too much optimism can leave the company exposed to substantial downside financial risk (which may even put the company's viability at risk). The literature on industry management and goals suggests that contractors are not, as often supposed by some, driven solely (or even largely) by the goal of making profits, *especially* when doing so makes other goals harder to attain. One major survey of defense contractors found that "contractors were virtually unanimous in their willingness to sacrifice short-run profit for the sake of (1) company growth; (2) an increased share of the defense market; (3) a better public image; (4) organizational prestige; (5) carryover benefits to commercial business; (6) opportunities for follow-on business; (7) greater expectations for further growth and profit."[11] Other surveys found similar results, with contractors ranking profits well below other goals, such as building a quality product and maintaining a good relationship with the buyer.[12] Over the long

[11] J. Ronald Fox, *Arming America: How the U.S. Buys Weapons* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1974), p. 441.

[12] Robert F. Williams, "So, What Does the Defense Contactor Really Want?" *Program Manager*, March-April 1983; Raymond G. Hunt et al., "Federal Procurement: A Study of Some Pertinent

run, though, contractors must achieve an acceptable rate of return on equity in order to attract investment capital and thus remain viable, even if they are willing to sacrifice short-term profits. There are also, to be sure, limits to a contractor's ability or willingness to forgo short-term profits, especially when there is little prospect that such short-term sacrifice will lead to a long-term gain. Contractors must balance the downside risk of being too optimistic on a program--and hence exposing themselves to large financial losses, loss of prestige, etc.--and the need to produce aggressive proposals in a competitive environment.

One aspect of contractor characteristics that emerged from interviews with Hughes Aircraft (HAC) personnel was their description of the company as highly tolerant of risk: HAC was considered an "engineer's" firm that stressed technological advance and design over profits. Solving engineering problems was more important than making money. In the words of one corporate manager:

> We're proud of our heritage, proud that the company started out as a small electronics company. . . . We were always dominated by engineers. The most important thing was overcoming technical challenges, to do something that couldn't be done. We didn't care about making money, and there were no demands placed by the parent. Five percent profit was plenty. The question was, "Can we solve technical problems?"

Others characterized the firm as "technologically aggressive, technically driven."

HAC was purchased by General Motors in 1985-1986, and personnel were unanimous in their view that GM has changed the company culture; in particular, managers are under far more pressure to improve profit and cash-flow positions:

> The GM-Hughes acquisition changed engineering dominance, the little concern with profits. There's no way HAC will allow that now. . . . We never had to talk about return on investment or cash flow before. Before the

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Properties, Policies, and Practices of a Group of Business Organizations," *National Contract Management Journal*, Fall 1970.

> acquisition, we invested our profits in technology. After, we have a fiduciary responsibility to our stockholders. And have an obligation to produce a profit.
>
> We've gone from "that's an interesting project" to "where's the payoff?"

One element of the changed environment is that the managers interviewed were evenly split on the question of whether HAC would have bid on AMRAAM had GM owned the company in 1981. While some argued that GM's concern about profits would have forced the company to no-bid, others note that HAC would have still bid, because of the need to stay in the missile business (indeed, this is one reason companies may be willing to tolerate higher risk levels, because the alternative is being shut out of future business opportunities altogether):

> There is only one program like this every 30 years, and programs last about that long, so you're driven to go after this work. It isn't always an economic decision, and sometimes it's a matter of staying in the business. . . . We knew the program was tough and that the government was unrealistic on the schedule. You have to bid to stay in the business.
>
> According to another manager:
>
> We would have bid on AMRAAM even if GM owned us then, so we could stay in the air-to-air missile business. We figured it would go on for 20-30 years and thought the quantities were too low; we thought we could sell more. We expected to make a lot of money.

Even though there are limits on how much risk a company will accept, it appears that company culture plays an important part in determining how aggressive a firm will be on a program and what level of risk is tolerated.

Though organizations may wish to minimize one or more types of risk, in an environment in which the organizations interact with each other, it will often be true that the steps one organization takes to minimize its own risk will increase the risk for another organization. This is especially apparent with

respect to government and contractor conceptions of financial risk. The Air Force's desire to minimize acquisition costs will often directly conflict with contractor desires to make a profit. Even though contractors will generally sacrifice short-term profit if doing so enhances other organizational goals (which presumably will increase profits in the long run), at the extremes the following statement must be true: contractors will refuse to bid on programs or insist that the requirements be changed if they think the financial risk is too high. While it is surely possible to reach an accommodation whereby both the government and the contractors are protected against risk--suitably priced fixed-price contracts, or various incentive-type contracts--much of the dispute in the mid-1980s over the use of fixed-price contracts for development work confronted this issue directly, with contractors claiming that using fixed-price contracts for high-risk programs placed unacceptable levels of financial risk on them (eventually the government agreed and backed off).

Competitive environments have a similar effect of transferring risk from the government to contractors. By encouraging contractors to bid aggressively in terms of both technology and price, in theory the government gains the advantage of lower costs and better performance. Yet competition can have perverse effects, particularly when contractors are willing to sacrifice profits for market share. The result of the need for careful management of competition and, to use the shopworn slogan, "avoiding competition for competition's sake" is that contractors are willing to tolerate short-term financial risk--involving forgone profits--in the pursuit of long-term goals; they are not simply profit maximizers (as noted above). One element of this is the common feature of "buying in" on research and development contracts: contractors are prone to understate development costs, taking a loss in this program stage, with the expectation that they will make up the loss during production (especially if production is sole source). The contractor's willingness to do this may well depend on how it assesses technical risks. Some

contractors may be more risk tolerant than others; corporate culture, the health of company finances, and the influence of top management will all shape a company's perception of whether a program is worth the risks involved and help determine the appropriate proposal strategy.

In some cases, competitive bidding environments may encourage contractors to promise too much, either by buying in or being overly optimistic about the level of performance they can attain. The government may thus find itself, once it is committed to a single development contractor, with a company short of money and nowhere near contract completion. At this point, there are few palatable options: the government can "hold the contractor's feet to the fire" and perhaps drive the firm into near insolvency with no guarantee that the final product will be ready or it can relax contractual restrictions (when using fixed-price contracts)--an act that will likely be seen by opponents of the program as a bailout.

If the government accepts the contractor proposal and transforms the technical and cost characteristics into firm system requirements,[13] it increases the risks of overselling; initial optimism can easily lead to long-term risk and instability.

In AMRAAM's case, one theme that emerged from the interviews is that the contractors simply promised too much, largely because each was concerned that a more realistic proposal would put them at a competitive disadvantage vis à vis the other. The problem was exacerbated, according to several contractor personnel, by the fact that the Air Force encouraged aggressive bidding and translated the winning proposal into a firm set of requirements.

[13]One analysis of the Cheyenne helicopter program noted that Lockheed proposed a system with a ferry range nearly twice what the Army considered to be feasible--2500 nautical miles against the original requirement of 1500 nautical miles. Nevertheless, the Army went along because, according to an Army official, "We did not know enough about the detailed technology with respect to the aircraft to know that it was not reasonable to expect that aircraft in its configuration to achieve that much ferry range." See Fox, p. 102.

The result was that HAC overestimated performance and underestimated costs and had to write off $255 million to cover overruns on the development contract.

Competitive environments can produce advantages to both the government and contractors by motivating contractors to improve the efficiency of their operations and by lowering costs while still achieving acceptable profit levels. Yet the government must be attentive to the perverse results that can occur.

# 2. A HISTORY OF THE AMRAAM PROGRAM

## ORIGIN AND REQUIREMENTS

The AMRAAM requirement originated in the mid-1970s from Air Force investigations into the air-to-air threat projected into the 21st century, which indicated the need for a significant improvement over the capabilities of the current medium-range missiles in the Air Force inventory. The AIM-7 Sparrow had a semiactive guidance system (receiver only) and required pilots to fly toward the target, illuminating it with the launch aircraft radar, as the Sparrow homed in on the reflected radar waves.[14] Both combat experience and simulations had convinced pilots and Air Force leadership that semiactive missiles put pilots at risk and made medium-range engagements little more than a function of which pilot fired first.[15] AIMVAL/ACEVAL (Air Intercept Missile Evaluation/Air Combat Evaluation) studies--simulations designed to assess the combat effectiveness of missiles and planes--also demonstrated that a single aircraft equipped with Sparrow was at an extreme disadvantage when faced with two enemy aircraft. Only one Sparrow could be fired per pass, so even if the friendly aircraft shot down one enemy, it was vulnerable to attack from the second aircraft. This one-to-one exchange ratio was considered unacceptable, largely because Allied aircraft were outnumbered by Soviet Union/Warsaw Pact aircraft in the European theater. In addition, the Sparrow had a limited capability against low-

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[14]The AIM-54 Phoenix had an active radar guidance and control system, but only the F-14 could carry the missile.

[15]Congressional Budget Office, *The Advanced Medium-Range Air-to-Air Missile (AMRAAM): Current Plans and Alternatives*, Staff Working Paper, August 1986, p.7n; testimony before Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 1979*, Part 7 (Tactical Air), p. 5250.

altitude targets and electronic countermeasures (ECM) and was costly to maintain and operate.[16]

The AMRAAM requirement was for a high-speed, highly maneuverable, beyond-visual-range (BVR) missile with a true "launch and leave" capability. The goal was to design an active guidance and control system, incorporating both a radar transmitter and receiver, that would allow AMRAAM to track targets on its own, without assistance from the launch aircraft. This would free pilots from the need to use the launch aircraft radar to track the target and allow them to engage multiple targets simultaneously. The size and weight of the missile were constrained by the desire to deploy it on the F-16 aircraft wingtip stations. The Sparrow, at 500 pounds, was too heavy; the initial estimate was that AMRAAM would weigh less than 350 pounds.

The Air Force wanted to attain this significant improvement over AIM-7 performance while keeping costs well below Sparrow levels. AMRAAM was to achieve higher reliability and lower life-cycle costs through the use of Large-Scale Integrated Circuits (LSIC) and a solid-state transmitter (SST), the technology for which was still evolving in the late 1970s. Control surfaces used electromechanical actuators instead of the hydraulic systems common in current systems. According to information provided at the DSARC I briefing, AMRAAM program costs were estimated at $2.031 billion (1978 dollars), while development and procurement of an upgraded sparrow, the AIM-7M, were estimated at $1.857 billion. The Air Force forecast that AMRAAM would achieve twice the combat capability of Sparrow at approximately one-half the cost, resulting in a fourfold increase in cost-effectiveness.

The Joint Strategic Operational Requirements (JSOR), validated by the Air Force in August 1978 and by the Navy in September 1978, set the baseline requirements for AMRAAM:

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[16]See briefing by Colonel Luke Boykin, AMRAAM Program Manager, to Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 1979, Part 7 (Tactical Air)*, p. 5248.

- Launch and leave capability;
- Multiple-target attack capability;
- Look-down, shoot-down capability (the ability to track and engage low-altitude targets against ground clutter);
- Improved warhead and reduced miss distance;
- Electronic counter-countermeasure (ECCM) capability;
- Low procurement and life-cycle costs; and
- Compatibility with the F-14, F-15, F-16, and F/A-18; British Tornado and Sea Harrier; and West German F-4G aircraft.

In 1977, before Congress zeroed funding for FY78, the AMRAAM schedule consisted of four phases, over nine years, prior to production. Concept definition would last one year, followed by a 36-month "Competitive Prototype Development" phase, during which two contractors would design and test AMRAAM prototypes. Full-scale development ("Engineering Development") would take three years, followed by two years of pilot production (low rate production). DSARC III was scheduled for late 1985, with first deliveries at the end of 1986.[17] At this stage, the program manager left open the possibility that the schedule could be compressed by up to two years if the prototyping phase went well.[18]

The congressional funding cut delayed the program by about six months, with DSARC III slipped to early 1986 and first delivery in 1987. In its 1978 formulation, AMRAAM development would still require about 90 months from DEM/VAL through production (encompassing validation and full-scale development), with pilot production to begin in 1985 and first deliveries in

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[17] Testimony before the Senate Armed Services Committee, *Fiscal Year 1978 Authorization for Military Procurement, Research and Development*, Part 6 (Tactical Air), pp. 4615-4618.

[18] Ibid., p. 4618

1987.[19] DEM/VAL was shortened from 36 to 33 months; the other phases remained at about the same length.

In 1978, the Commander of Air Force Systems Command reduced the 90-month development schedule to 70 months, primarily by eliminating pilot production altogether and accelerating some development tasks into the prototype/validation phase. The idea was to produce a missile close to the production configuration by the end of DEM/VAL and concentrate on producibility issues during FSD. Production was now scheduled to begin in early 1984, first delivery and IOC at the end of FY85. According to program histories and interviews, this decision was made to permit AMRAAM deployment on F-16 aircraft scheduled for delivery to Europe in 1986. At the time, the F-16 was considered an excellent aircraft, but one lacking any sort of medium-range capability; it was described by one former SPO official as "a fabulous airplane with no protection." In August 1978, AFSC approved a 73-month development effort (33 months for DEM/VAL and 40 months for FSD). The Air Force briefed the House Armed Services Committee on the revised schedule, estimating the probability of successful execution at about 60-70 percent.[20] Table 2.1 displays the AMRAAM program schedule at several different points.

From the beginning, AMRAAM was a highly concurrent program, with combined Contractor Development Testing and Evaluation (CDT&E) and Operational Testing and Evaluation (OT&E) to take place in the latter half of FSD. The compressed 73-month development schedule introduced additional concurrency, as it assumed that much of the development work would be completed during validation; moreover, it required that the production decision be made before completion of FSD (unlike the original

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[19]Testimony before Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 1979*, Part 7 (Tactical Air), p. 5255.

[20]General Accounting Office (GAO), *Missile Procurement: AMRAAM Cost Growth and Schedule Delays* (GAO/NSIAD-87-78, March 1987), p. 13.

Table 2.1

Schedule Changes for AMRAAM

| Milestone | Original Plan 3/78[a] | Revised Plan 8/81 | Revised Plan 12/82 | Revised Plan 9/85 | Actual |
|---|---|---|---|---|---|
| DSARC I | 1QFY79[b] | | | | Nov 78 |
| FSD contract | 1QFY82 | Nov 81 | | | Dec 81 |
| DSARC II | 1QFY82 | | Sept 82 | | Sept 82 |
| DSARC IIIa | 2QFY85 | | Nov 84 | Apr 87 | June 87 |
| 1st Prod Del | 4QFY85 | June 85 | Aug 85 | June 88 | Oct 88 |
| JRMB/DAB IIIB/full-rate prod app. | --- | | | | Apr 91 |
| IOC | Sept 85 | Sept 85 | 4QFY86 | 3QFY89 | Jan 91 |

SOURCE: Jeffrey A. Drezner and Giles K. Smith, *An Analysis of Weapon System Acquisition Schedules*, RAND, R-3937-ACQ, December 1990, Appendix C; briefing by Colonel Luke Boykin before Senate Armed Services Committee on Fiscal Year 1979 Air Force Budget Request, March 1978; testimony of Honorable John J. Welch, Assistant Secretary of the Air Force (Acquisition) before House Armed Services Committee, March 13, 1991; General Accounting Office, *Missile Procurement: Further Production of AMRAAM Should Not Be Approved Until Questions Are Resolved* (GAO/NSIAD-90-146, May 1990).

[a]With 70-month development phase.

[b]QFY--quarter, fiscal year.

schedule, in which the production commitment would occur after FSD, during the pilot production phase).

The schedule began to slip almost immediately upon the start of the validation phase. Neither Hughes nor Raytheon was making the anticipated progress toward achieving a mature missile design by the end of validation (something that JSPO officials were aware of by mid-1980). Hughes was unable to incorporate a solid-state transmitter design into the missile, largely because it could not generate sufficient power, and before the end of validation had abandoned the SST in favor of a traveling wave tube (TWT).[21] In addition, neither contractor was able to incorporate LSIC technology into their respective designs. According to the

[21]Hughes made this decision because it was experienced in TWT technology and was confident in its ability to manufacture TWTs in quantity.

General Accounting Office, Air Force and Hughes engineers noted that "more large scale integrated circuits could have been incorporated into the AMRAAM's design had the program's schedule not been compressed."[22] Instead of integrated circuits, Hughes relied on "hybrid" circuits, which comprise highly miniaturized discrete components. These took up more space, required more power, and generated more heat than integrated circuits. They were also more expensive to manufacture and package, and required special mounting technologies (ceramic cards instead of cheaper standard circuit boards) to dissipate excess heat.

The original DEM/VAL effort called for the contractors to test fire ten prototype missiles each, but Raytheon was able to test only five missiles, Hughes three. Rather than continue testing, the JSPO "established a 2 December 1981 cutoff for flight testing to support the source selection," which occurred on 7 December 1981.[23] Neither contractor had achieved stable missile design, but the Air Force decided to end the Validation phase on schedule and push back some design efforts into FSD.

During DEM/VAL, both contractors expressed concern that the 40-month FSD schedule was optimistic, and neither would bid on the basis of that schedule. As a result, the Air Force lengthened the FSD schedule by ten months and slipped IOC from September 1985 to August 1986.

While there was no documentation in the SPO that indicated how much attention the SPO paid to it, a 1980 General Research Corporation study estimated the probability of completing the 40-month FSD phase on time. That risk analysis evaluated 97 FSD tasks and estimated a 0 percent probability of completing the tasks in 40 months, rising to 100 percent certainty by 48

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[22]GAO, *Missile Procurement: AMRAAM Cost Growth and Schedule Delays* (NSIAD-87-78), March 1987, p. 16.

[23]Department of the Air Force, HQ Armament Division, *FY 83 Armament Division History*, p. 152.

months.[24] In 1982, the Armament Division considered schedule risk "high" in the revised 50-month effort.[25]

Key members of Congress, including House Armed Services Committee staff member Tony Battista, were lukewarm about AMRAAM because of affordability concerns and the issue of a new system start versus upgrading current systems. AMRAAM development was considered along with upgrading the Sparrow with an advanced monopulse seeker (AMS), an option the Air Force considered and rejected.[26] In addition, in hearings Congress exerted some pressure on the Air Force to develop one missile to fulfill three combat roles: the Advanced Intercept Missile, a longer-range system that would be a follow-on to the AIM-54C Phoenix; AMRAAM; and the Shipboard Intermediate Range Combat System (SIRCS), a follow-on to the RIM-7F Sea Sparrow missile, a shipborne air defense system.

**ACQUISITION STRATEGY**

AMRAAM SPO personnel emphasized that AMRAAM was one of the first programs to be conducted in compliance with Acquisition Circular A-109, which set out the significant steps for conducting major system acquisition. A-109 stressed the importance of giving contractors design freedom to meet performance requirements instead of the more traditional model of the government's specifying exactly what the contractors must build. During the concept validation phase that preceded DEM/VAL, for example, the five contractors produced very different designs, which gave the Air Force freedom to determine which approach could best meet its requirements. Though, as noted below, this early flexibility had some unintended consequences, especially with regard to cost

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[24]Joseph Large et al., *Cost Estimates and Estimating Procedures in the IIR Maverick and AMRAAM Programs*, RAND, R-3584-AF, May 1988, p. 49.

[25]Ibid., p. 49.

[26]Though the AMS would increase the accuracy of the Sparrow, and hence its $P_k$, it would not provide a launch-and-leave capability. In addition, the upgraded Sparrow would still be too heavy for the wingtip stations of the F-16.

estimating, SPO personnel thought the arrangement worked very well.

The AMRAAM program involved competition from the beginning. During concept definition, five contractors did feasibility and design studies (Hughes, Ford Aerospace, General Dynamics, Northrop, and Raytheon). From a competitive negotiated procurement, two contractors were selected for the prototype validation phase, with a single contractor selected for FSD. The Air Force planned to compete annual production buys with a leader/follower strategy, and the second-source qualification process was initiated very early in FSD. The Air Force awarded Hughes the FSD contract in December 1981; in July 1982, Raytheon won the contract to become the second source. The goal of the second-source plan was to initiate competitive leader/follower procurement by the fourth production lot, with a 60-40 split. During FSD, Hughes was, in effect, to teach Raytheon how to manufacture the missile.

Both Congress and OSD were intent on introducing competition whenever possible in acquisition programs,[27] and the Air Force was under substantial pressure to incorporate a second source into the AMRAAM program. "Lot's of people wouldn't accept programs without a second source," one SPO official said, "so we had to have competition." According to Hughes Aircraft Corporation personnel, the second-source requirement was introduced shortly before both HAC and Raytheon were to submit their best and final offers on the FSD program.

The FSD contract was fixed-price incentive, with a ceiling price of $526 million (see Table 2.2). In addition, the contract contained two prepriced production options, which had the advantage of committing the contractor to initial production prices when competition still existed. One study of AMRAAM argues that Hughes insisted that the production options be exercised by a "specific date, rather than on the basis of progress in

[27]"Pentagon Urges Competition on Missile," *Aviation Week and Space Technology*, 27 July 1981, pp. 58-60.

Table 2.2

FSD Contract Details

| | |
|---|---|
| Contract type | fixed-price incentive |
| Target price | $421 million |
| Ceiling price | $526 million |
| Share ratio | 85/15 |
| Warranties | storage reliability for production units |
| Prepriced production options | 11/1/84 (204 missiles, $273 mil)<br>11/1/85 (720 missiles, $486 mil) |

development."[28] This contract structure had the effect of reducing some of the risk Hughes assumed through a fixed-price contract: if Hughes fell behind and was not ready to enter production by the option date--or, more properly, if the program had not progressed to the point where the Air Force could exercise the options within 180 days--the options would be nullified and the government would have to renegotiate the initial production lot prices (Raytheon insisted on this provision as well). HAC personnel confirmed this interpretation; they claimed that HAC knew that the program was ambitious and expected that problems would develop that would prevent the Air Force from exercising the options (one official claimed that HAC was hoping for this outcome). HAC was thus somewhat insulated if the final production costs exceeded the early estimates.

Hughes fell behind schedule almost immediately. "An independent schedule assessment by General Research Corporation (GRC) completed in June 1982, about 6 months after contract award, predicted a 2 to 4-1/2 month delay in the start of guided flight tests and a possible 7-month delay in the availability of software tapes needed to complete tests with the F-16."[29] An undated briefing chart obtained from the AFSC Historical Office indicated that the GRC study predicted only a 1 percent chance of completing FSD in 50 months.

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[28]Thomas L. McNaugher, "Weapons Acquisition: Bleak Prospects for Reform," *Brookings Review*, Summer 1986, p. 12.

[29]GAO, *AMRAAM Cost Growth and Schedule Delays*, p. 14.

After a preliminary design review held at Hughes in August 1982, the Air Force found the Hughes design "conditionally acceptable" because the "development status of certain system components was relatively immature."[30] Nevertheless DSARC II approval to proceed into FSD was granted in November 1982, nearly one year after the FSD contract had been awarded.

In December 1983, Hughes formally notified the Air Force that it would be unable to meet the original FSD schedule and proposed a 53-month schedule with 122 deliveries.[31] Also in that month, staff of the House Armed Services Committee completed a Production Readiness Review--an Air Force report on the visit predicted that House Armed Service Committee authorization language on the AMRAAM program as part of the FY85 budget

> will probably be extensive and will place restrictions on the use of production funds pending certification of certain completed actions or correction of problems. The exact nature of these are unknown. The Air Force will be at a definite disadvantage as a result of this situation, being forced to rebut the language without prior knowledge of the Committee's conclusions.[32]

As a result of continued problems at Hughes with the program schedule, the Air Force reduced award fee payments. Possibly because of the reduced payments, Hughes notified the Air Force in April 1984 that without accelerated funding (which involved more rapid obligation of contract funds and not an increase in the contract amount), it would unilaterally alter the program's schedule because of inadequate funding. Hughes also claimed the right to request that the contract price be adjusted as an alternative to simply stopping work when the contract funds were exhausted.[33] By May 1984, Hughes was claiming that it could not

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[30] USAF, Armament Division, Wright-Patterson AFB, *FY 83 Armament Division History*, p. 179.

[31] *History of the Deputy for AMRAAM*, 1 October 1983–30 September 1984, p. 3.

[32] Department of the Air Force, Information Memorandum, *Trip Report--HASC AMRAAM Production Readiness Review (PRR)*, 14 December 1983, p. 5.

[33] Correspondence between HAC and JSPO, 24 April 1984.

meet the 53-month schedule it proposed in December 1983 and that FSD completion would be delayed another seven months, from May to December 1986.[34] HAC also was arguing that it was justified in restructuring the program "since both the AF and HAC were over-optimistic from the beginning" and because it "[needed] more time to do [the] job right."[35] In July, HAC and the Air Force agreed to restructure the program, eventually extending FSD by an additional ten months (to 60 months) and reducing the number of test missiles from 122 to 80. In addition, certain ECCM capabilities would be delayed and introduced into production missiles during a Pre-Planned Product Improvement ($P^3I$) phase to take place after FSD; 15 Lot I missiles would be fully ECCM capable.[36]

**INCREASING EXTERNAL OVERSIGHT**

AMRAAM troubles led to an OSD-directed review beginning in January 1985. That review had two parts: an evaluation of methods to reduce AMRAAM production costs and an assessment of the impact of implementing any cost reduction efforts identified. The evaluation also looked into alternatives to AMRAAM "that might yield a more cost-effective solution to the military requirement."[37] During this period, the program office lengthened the FSD program to 79 months, retaining the original scope of the FSD effort. The FSD contract price was not renegotiated, and Hughes was forced to pay for any overruns (estimates are that Hughes spent $255 million of its own money on AMRAAM development). The options for Lots I and II were delayed until 1987 and 1988, respectively, which required that the prices be renegotiated (the quantities were slightly larger than the original quantities--260

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[34] *History of the Deputy for AMRAAM*, FY 1984, p. 7.

[35] Memorandum for the Record, *AMRAAM Meeting, Eglin AFB*, 11 May 1984.

[36] *History of the Deputy for AMRAAM*, 1 October 1983-30 September 1984, p. 3.

[37] Robert R. Ropelewski, "Defense Department Orders Delay in AMRAAM Production Decision," *Aviation Week & Space Technology*, February 4, 1985, p. 25.

Lot I and 833 Lot II missiles--but the contract allowed the government to adjust the number of missiles it purchased under the options; IOC was moved to 1989. Even after this restructure, the program was still concurrent: low rate production was slated to begin before completion of OT&E.

In October 1985, Deputy Secretary of Defense William H. Taft IV directed the Air Force to complete the following tasks within 60 days:[38]

- Submit recommended decision criteria to the mid-1986 DSARC program review.
- Submit a detailed description of the AMRAAM Producibility Enhancement Program (APREP).
- Add definitive test goals and thresholds to the Test and Evaluation Master Plan (TEMP). All guided missile tests and associated events must be reported to Director, Defense Test and Evaluation.
- Report progress on reliability thresholds at program and milestone reviews.

The most significant element of this direction was the APREP, an effort to identify ways of lowering the production cost of the missile. The idea was to incorporate selected design changes into the missile on an incremental project basis, subject to the following conditions. First, the design changes could not lower system performance. Second, the projects identified must be considered low to moderate risk, with a high return on the initial investment (the individual projects would require an up-front expenditure). Finally, all changes had to be form, fit, and function compatible with the existing aircraft interfaces.[39]

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[38]Robert Robelewski, "AMRAAM Meets Funding, Program Review Setbacks," *Aviation Week & Space Technology*, November 4, 1985, pp. 29-30.

[39]*Advanced Medium-Range Air-to-Air Missile (AMRAAM) Decision Coordinating Paper*, Annex E, 25 November 1985, p. E-5.

The Air Force estimated that the APREP effort would require an up-front investment of $330 million but would yield long-term savings of $1.3 billion in AMRAAM production. Funding for APREP projects would be retained by the DoD Comptroller and would be released incrementally. The major projects identified in the initial APREP effort consisted of changes to the guidance and control system, while other projects dealt with the rocket motor and control systems. An important design change identified early in the APREP process was incorporating Large-Scale Integrated Circuits (LSIC) and Very-High-Speed Integrated Circuits (VHSIC). Much of the APREP effort involved identifying and redesigning high-cost AMRAAM components. APREP allowed Hughes to incorporate some advanced technologies that it was unable to use in the earlier versions of the missile because of schedule demands. By taking into account savings from the various APREP projects, the Air Force lowered the program estimate for AMRAAM from about $10.2 billion to $8.2 billion.

Most sources in the SPO and with the contractor spoke in positive terms about APREP. The consensus is that the redesign effort was necessary because the cost of the missile was too high, and the program provided an opportunity to take advantage of technical advances that had occurred since the original design effort. This outweighed the risks of attempting a major redesign so late in the program. One contractor manager stated, "I thought we were nuts to try a new design at that point, but the phasing has worked out. APREP hasn't hurt the program; it was the right thing to do because it has driven down the price of the missile."

In 1985, congressional dissatisfaction with the program manifested itself in language attached to the FY86 defense budget, which established detailed reporting and certification requirements for the AMRAAM program. The FY86 Defense Authorization Act required the Secretary of Defense to certify to Congress by March 1986 that:

- The AMRAAM design is complete.

- System performance has not been degraded from the original development specification.
- The maximum practical number of cost reduction design changes have been incorporated into the flight test program and qualified before production.
- FSD costs will not exceed $556.6 million.
- Total production costs will not exceed $5.2 billion in 1984 dollars for 17,000 missiles (Air Force inventory).

Although this was not the first instance of congressional attention to the program (GAO had been critical of AMRAAM since at least 1981), it was the first time Congress had attached such stringent requirements on the program as a condition for continued funding. Secretary of Defense Weinberger issued the required certification on February 28, 1986 (see Table 2.3). The $556.6 million ceiling on the FSD contract was actually about $200,000 *less* than the amount of money that had been obligated to that point. As a result, the JSPO modified the FSD contract in December 1985 to relieve Hughes of the responsibility to inspect and repair three reliability test vehicles, reducing the amount obligated under the contract by $412,000.[40] The SPO also argued that the FSD contract ceiling would hurt the testing schedule by preventing the Air Force from establishing a third test site at Eglin Air Force Base, Florida.[41] In July 1986, the General Accounting Office issued a report questioning Weinberger's certification of the AMRAAM program.[42] Based on the certification, Congress approved continued program funding but reduced funding and procurement quantities for Lots I and II, from 260 and 833 to 180 and 630 missiles, respectively.

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[40] U.S. Congress, House of Representatives, *Department of Defense Authorization of Appropriations for Fiscal Year 1987*, Title I, p. 838.

[41] "GAO Questions AMRAAM Certifications," *Aerospace Daily*, 7 March 1986, p. 362.

[42] *Missile Development: Advanced Medium-Range Air-to-Air Missile (AMRAAM) Certification Issues*, GAO/NSIAD-86-124BR, July 1986.

Table 2.3

Assumptions Behind 1986 Cost Certification

| |
|---|
| AMRAAM cost certification of $5.2 billion (1984$) for a minimum of 17,000 missiles assumed that |
| – AMRAAM would be funded at $1 billion annually (joint service) for 9 years beginning in FY88 |
| – A Navy buy of 7,212 would begin in FY89, for a total production buy of 24,335 missiles |
| – A full production rate would be maintained for 7 years starting in FY90; this does not include potential foreign sales |
| – Cost reduction design changes would be fully incorporated into production Lots III and IV in 1989 and 1990, respectively |
| – APREP cost reduction design changes would reduce costs by $1.7 billion for joint Air Force/Navy procurement ($1.2 billion attributable to Air Force procurement) |
| – No model changes or major design changes would be made for 10 years |
| – Large savings accrued from competition at both prime and subcontractor levels |
| – Unit production costs will drop from $3.1 million per missile in 1987 (including nonrecurring startup costs) to $360,000 in then-year dollars in 1990 |

The following year, Congress established another set of requirements for AMRAAM and set a ceiling of $7 billion for procurement of 24,000 missiles. In addition, the congressional restrictions stipulated that no funds could be obligated for procurement (except long-lead items) until AMRAAM successfully completed a two-on-two test in an ECM environment. The first attempt at this so-called "congressional shot" failed, in part, because of problems with the launch aircraft radar.[43] The second test was originally scheduled as an operational test, under the

[43]GAO, *Development Status of the Advanced Medium-Range Air-to-Air Missile*, p. 20.

control of the Air Force Operational Testing and Evaluation Center (AFOTEC); it consisted of two targets in a more severe ECM environment and involved jamming both the missile and launch aircraft radars and a screening jammer in one of the targets.

Several sources noted that the SPO revised certain elements of the test process; according to the GAO, these changes were considered unacceptable to AFOTEC and the test was redesignated a developmental test under SPO control. The changes to the key test involved increasing the distance between the targets, changing the characteristics of the target jammer, and deleting the aircraft radar jamming.[44] On the first attempt, the test was aborted because of a wiring problem in one of the missiles. The test was successfully completed on April 29, 1987.

More recent problems include production transition problems at Hughes and problems with the F-15 environment. In 1989, the Air Force discovered that the F-15 captive-carry environment was much more severe than anticipated: when pilots reduced engine speed, air spilled from the intakes, causing extreme vibration in the missiles. The vibration caused fins to crack and damaged some internal circuitry. None of the problems was a showstopper, but all required time, effort, and money to fix. SPO personnel had much to say about the F-15 problems. The missile was designed to deal with aircraft environments based on data provided by the different aircraft programs. The problem, according to one official, was that nobody had told AMRAAM about the deceleration spillover problem on the F-15, which meant that the SPO engineers were unaware of the severity of the F-15 environment: "We did everything right--we had all the right groups, and all the right inputs, and had problems with the Sparrow, but there was no communication from the AIM-7 folks, nobody told us about the problem. This part of the envelope was never shown to us; if we

[44] *Development Status of the Advanced Medium-Range Air-to-Air Missile*, p. 21; Rowan Scarborough, "GAO Says Changes to AMRAAM Test Enhanced Success," *Defense Week*, June 8, 1987; Rowan Scarborough, "Air Force Changes Test to 'Enhance' Odds for AMRAAM," *Defense Week*, April 20, 1987.

had known about it from the beginning, we could have designed for it from the start." These problems have been corrected with modifications to the missile airframe and electronics.

It now appears that the missile will meet the performance requirements originally envisioned. In 1985, the Air Force reduced the F-Pole requirement and the launch-to-eject time requirements slightly, but the missile retains the valued launch and leave capability and will meet the size constraints for deployment on F-16 wingtip stations. The problems that remain have more to do with the contractors' ability to produce the missile in large quantities. The missile still faces substantial opposition in Congress, and opponents have capitalized on a number of critical GAO reports that have questioned missile reliability. In late 1989, GAO argued that AMRAAM was not ready for full-rate production.[45] In May 1990, the GAO recommended that Congress not approve additional procurement funds, noting that "significant questions about AMRAAM's performance, reliability, producibility, and affordability remain unresolved."[46]

Despite the GAO's pessimistic evaluation, Congress has continued to fund the program, though at reduced quantities. In FY92, Congress authorized 891 missiles (from an initial request of 1,250 missiles). Continued controversy exists over the questions of affordability and readiness for full-rate production, but these problems are not considered showstoppers. However, the program has achieved the technical goals originally sought, though the development phase was much longer and more expensive than originally anticipated. The question addressed in the following section is whether the management practices in the SPO and the direction of higher-level Air Force command authorities had an adverse impact on the program and whether those practices were consistent with the degree of risk in the AMRAAM program.

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[45]General Accounting Office, *Missile Procurement: AMRAAM Not Ready for Full-Rate Production* (GAO/NSIAD-89-201).

[46]General Accounting Office, *Missile Procurement: Further Production of AMRAAM Should Not Be Approved Until Questions Are Resolved* (GAO/NSIAD-90-146).

## 3. AREAS OF RISK IN THE AMRAAM PROGRAM

> An air-to-air missile is the hardest thing there is to develop. The testing is so hard to do, and you have to do so many of them. You have targets and target conditions that are 20 times harder than any other kind of program. Air-to-air missile development times should be the longest thing there is, even more so than airplanes.
>
> AMRAAM SPO official

> [An air-to-air missile] must mate with any of the fighters, accept inertial mid-course guidance from that aircraft, fly to a point in space, and using its own radar intercept within lethal range of targets which have all sorts of countermeasure equipment, evade with high "G" maneuvers, and must be encountered from any flight aspect . . . the missile must make a successful low rate closing in rear attacks and also intercept targets in high rate (Mach 5) frontal attacks. The warhead proximity fuse must insure a kill in any sort of terminal encounter at the wide range of closing rates.
>
> Colonel Luke Boykin, USAF (ret),
> AMRAAM program manager, 1976–1980[47]

The Air Force and the contractors both knew that the AMRAAM program entailed substantial technical risk; there was indeed a high probability that the technical goals would be very difficult to meet. That in itself is not a problem, as virtually every major new program entails such risk, but few experience the severity of problems that existed in AMRAAM development. Three additional factors exacerbated AMRAAM risk: first, the program was subjected to extensive external direction, by Systems Command early in the program and by Congress and OSD later, that hurt the SPO's ability to manage effectively. In effect, AMRAAM was expected to meet a number of requirements that originated from *outside* the program office and that both raised the likelihood that "adverse events" would occur and hampered the SPO's flexibility in responding to those events. While nearly all major

[47]Unpublished letter to *Aviation Week & Space Technology*, dated 21 May 1990.

programs are affected to some degree by such demands, in AMRAAM's case these external requirements were inappropriate for such a technically ambitious program; from a risk-management standpoint, they were simply unwise. Second, AMRAAM advocates did a poor job of managing the expectations of external actors, especially in Congress, leading to heightened awareness and criticism of the program once problems developed. And once the program achieved high visibility, criticism began to mount--over what now appears in retrospect to be the inevitable failure of the program to meet the early ambitious goals. The time SPO officials spend responding to criticism diverts attention away from actual program management and may even prod the SPO to become highly risk averse. In this case, the overriding goal moves away from the long-term achievement of technical or performance goals, toward minimizing the chance of any short-term failure. The program promised to deliver too much performance too quickly and at too little cost. Third, the general program management philosophy within the government appears to have been inconsistent with the level of risk inherent in a program of this sort.

**TECHNICAL RISK IN THE AMRAAM PROGRAM**

According to several SPO sources, the Air Force did a comprehensive risk assessment on the AMRAAM program in 1978, identifying the areas that posed the greatest technical challenges and evaluating management strategies and alternatives. One SPO official, who was with the program at the time, said that the assessment "was not just lip service." The areas of highest risk were the solid-state transmitter, multiple-aircraft capability, and software development--precisely the areas where the SPO and contractors had the most difficulty (see Table 3.1).

SPO engineers were confident that the technology for the solid-state transmitter would be available when necessary. Hughes had been studying the technology, using IR&D money, since the early 1970s and had demonstrated that the technology would work using breadboard prototypes. The technical questions involved the

Table 3.1

Areas of Risk Identified by the Air Force, 1978

- Multiple-aircraft capability (avionics integration, data link)
- Solid-state transmitter (power, cooling, reliability)
- System software (multifunction capability, Kalman filter implementation)
- Problem-solving fuze
- Missile environment (radome, cook-off, body flexure, heat dissipation)
- Commonality impacts
- Government hardware in-the-loop hybrid simulation (target signal generator)

ability to generate sufficient power--production AMRAAMs would require an order of magnitude improvement in power generation from the original demonstration designs--and the producibility of the design. There were contingency plans for reverting to the traveling wave tube, according to an SPO engineer, a technology that the engineers knew would work but was not "all that well planned out because of the high confidence in the SST." That confidence was not borne out: Hughes was unable to achieve the power output required from the SST. Both contractor and SPO personnel indicated that engineers still cannot design an SST powerful enough for use in a missile.

When Hughes decided during DEM/VAL to abandon the SST in favor of the traveling wave tube, the problem then became one of fitting all the parts into the missile container. Several SPO sources spoke of the difficulty of "getting the missile inside the missile" (the AMRAAM radar system is often compared in complexity to either the F/A-18 or the F-16 radar system). Simply increasing the diameter of the missile was not a feasible solution because that would increase the weight beyond the F-16's capabilities: although the Sparrow is only 1 in. larger in diameter than AMRAAM,

it weighs 50 percent more. As diameter increases, so does drag and weight, which requires a larger rocket motor, which increases weight again. Eventually, the front section of the missile was increased by 1/4 in., which affected weight, drag, velocity, and range. Because of the firm requirement that the missile be small enough to fit the wingtip stations of the F-16, the SPO did not consider further increases in diameter or weight.

Apart from the technical problems of designing a complete active radar system in a 7-in. tube, designers had the additional problem that the missile had to be compatible with seven different aircraft from three nations. In effect, the missile had to work seamlessly with different airframes, radar systems, and interfaces.

It is generally agreed that the technical problems in the AMRAAM design have been solved. The remaining problems involve the stability of the design (especially as they relate to the Raytheon and Hughes missiles; one source estimated that there are approximately 4,000 differences between the two designs, though performance is not, apparently, affected), the reliability of the missile, and the ability of the contractors to produce it in quantity. A related issue is the continued controversy over the missile's cost.

Nearly everyone in the program spoke of the risk of "unknown unknowns" as the chief cause of AMRAAM's technical woes. The risk assessment relied on projections that a technology on the horizon would be available when needed when that prediction failed to come true, the system had to undergo significant redesign. From an SPO engineer: "We had what we thought was a conservative predictor of the technology, but sometimes it just doesn't happen. You can do everything to minimize the impact, but you can't deal with 'unknown unknowns.'" Though, as noted above, the SPO did apparently consider what would happen if the SST technology did not mature as planned, engineers had bet heavily on the SST as a way to meet performance, size, and weight constraints. Interview data produced no clear evidence, but two possibilities suggest

themselves as an explanation for the impact of the SST failure on the program. First, the high initial confidence in the SST may have diminished enthusiasm for contingency plans to revert to the traveling wave tube; engineers may simply not have taken seriously the possibility that the SST might not work. The SST failure thus may have been more of an "ignored unknown" than an "unknown unknown." Second, given the advocacy needs of programs in their initial stages, it is possible that a formal and visible contingency plan may have been viewed by external authorities as a sign that the SPO was not confident that the SST would work as planned. In any case, there is no question that the SST's failure was a major setback to the program.

**THE IMPACT OF SCHEDULE ON PROGRAM RISKS**

Other things being equal, shorter schedules increase one type of risk--cost growth or performance degradation due to the inability of a program to work around technical problems--even as they lower the probability of fielding an obsolete system. Policymakers in the defense community had long been concerned about the length of the acquisition cycle, and by the mid-1970s, there was virtually unanimous agreement that it took far too long to move programs from conception to operational capability.[48] In 1986, the Packard Commission criticized the cycle as "unreasonably long . . . ten to fifteen years for our major weapon systems."[49]

It was against this backdrop that the Air Force made the initial decisions about the AMRAAM development schedule. Congress had placed both formal and informal demands on the Air Force to shorten the AMRAAM schedule; this pressure to reduce the acquisition cycle for AMRAAM appears to have been an important

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[48]This was not a new problem but one that had become worse as weapons systems became more complex. The Air Force had dealt with the problem in the past with production concurrency, dating back to the F-100 program in the 1950s. See Thomas L. McNaugher, *New Weapons, Old Politics: America's Military Procurement Muddle* (Washington, D.C.: Brookings Institution, 1989), p. 34.

[49]President's Blue Ribbon Commission on Defense Management, Final Report to the President, *A Quest for Excellence* (Washington, D.C.: Government Printing Office, 1986), p. 47.

factor in Air Force decisions on schedule compression. In 1977, for example, Raytheon executives met with House Armed Services Committee staffer Tony Battista; their notes from the meeting noted that Battista supported a new missile development but wanted a short schedule: "[Battista] believes a new missile development is required (after all he initiated the program), and would approve such a development if presented with a reasonable program. To him, *reasonable* means short--like three years to a production design."[50]

Another major driver of the AMRAAM schedule was the Air Force's desire to achieve IOC in time to deploy the missile on F-16s that would be sent to the European theater in 1985. This, according to some, was the main driver: "We had a fabulous airplane with no protection. To compete with other planes, it had to get into a dogfight and had no medium-range missile; it needed a BVR missile . . . we could have 'Band-Aided' AIM-7s on, but this was not a real solution. The F-16 issue pushed it more than anything else." An SPO source noted that the F-16 requirement was so vital that "some thought was given to taking validation missiles and going direct to IOC on the F-16."[51]

The first AMRAAM schedule was approximately 94 months, as noted above: one year of concept definition, three years of competitive prototype development, three years of full-scale engineering development, and two years of pilot production. IOC would be achieved about halfway through pilot production or by the end of 1986. However, in 1978, a working group in Air Force Systems Command directed that the schedule be shortened and eliminated pilot production. According to a senior SPO official at the time:

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[50]Letter to Raytheon headquarters, 23 May 1977.

[51]According to a former OSD official, another reason for the F-16 requirement is that key elements of the Air Force were unenthusiastic about the F-16 as the "low" end of the high-low mix of F-15 and F-16 fighters. Equipping the F-16 with the AMRAAM, according to this official, gave the Air Force the ability to significantly upgrade the aircraft radar and move away from the "dogfighting" doctrine that drove the original F-16 program.

> After the first schedule, there was a push from senior Air Force officials to get as close to the F-16 IOC as possible. We [the SPO] were between a stump and a hard place. We briefed the longer schedule, but there was a senior-level group that met, and they wanted us to cut off a couple of years. We compromised by cutting off a year.

Other SPO personnel spoke of the schedule reduction as being imposed by "superior rulers."[52] This schedule reduction is one of a small number of important external demands placed on the program.

The shortened schedule demanded that everything go right on the program: "We figured that if everything went perfect, we could do it." An SPO engineer commented that the reduction was the major factor that drove risk to unacceptably high levels: "The overall risk was moderate, when you look at everything, except when we went to the shorter schedule; that drove risk too high."

Because of the requirement that IOC be achieved by 1985, the SPO was reluctant to slip the schedule when problems arose. Neither contractor was able to complete missile design or testing during DEM/VAL as originally intended. Yet rather than delay the start of FSD, the SPO chose to end Validation on time and slip some design tasks into FSD. This prevented the program from taking full advantage of technologies "on the horizon," which could have been incorporated into the missile given additional time. Many of these technologies (especially LSICs and other microelectronics advances) were integrated as part of the APREP redesign effort. The contractor had to "Band-Aid" some problems, but none was really a showstopper.

It was clear by the end of DEM/VAL that the FSD schedule was unrealistic, as neither contractor was willing to bid on a 40-

[52]Note that these comments rely on the recollections of personnel involved in the decision at the time, some of whom are still with the program. It is not clear how much opposition there actually was at the time the schedule reduction was mandated.

month effort. The additional ten months did not solve the problem: halfway into FSD, Hughes notified the Air Force that it could not meet the schedule, and within two years the program was restructured to add an additional 25 months to FSD. Problems with production processes and reliability continued to delay full-rate production. SPO officials noted that there are AMRAAMs in the inventory (some were sent to the Persian Gulf, though apparently none was fired), though it is not clear if it has officially achieved IOC.

The ambitious nature of the AMRAAM schedule is apparent, given the history of air-to-air missile development programs (Table 3.2). It is difficult to make direct comparisons across programs because of differences in the nature of technical advances involved. Yet by most standards, the original AMRAAM schedule was quite short, particularly when compared to the most analogous new system development, the AIM-54A Phoenix missile, also built by Hughes. Like AMRAAM, the Phoenix incorporated an active guidance system but was less technically challenging for two reasons. First, the AIM-54 was used on only one aircraft, the F-14 Tomcat, and hence did not entail the integration complexity of AMRAAM (which was designed to fit on seven different aircraft). Second, the AIM-54 was a much larger missile: while the AMRAAM was only 7 in. in diameter, the Phoenix was 16 in. in diameter, giving engineers over four times as much volume (the original A model Phoenix did not incorporate solid-state technology). Even so, the Phoenix schedule was nearly twice as long as that for AMRAAM. AMRAAM's schedule is more comparable to missile upgrade programs. The actual schedule, with an approximate IOC date of mid-1990, was nearly 60 months longer than the one proposed (which puts it into the same range--approximately 133 months--as the AIM-54A).

The premise of the compressed AMRAAM program was that the contractors would be able to approximate the production design at the conclusion of DEM/VAL. Most contractor personnel interviewed

Table 3.2

Development Time for Air-to-Air Missiles

| | AIM-9M | AIM-7F | AIM-7M | AIM-54A | AIM-54C | AIM-120A[a] |
|---|---|---|---|---|---|---|
| Approximate length of development phase | 64+ | 117 | 95[b] | 132 | 71 | 73 |
| Type of program | upgrade | upgrade | upgrade | new | upgrade | new |

SOURCE: M. B. Rothman, *Aerospace Weapon System Acquisition Milestones: A Database*, RAND, N-2599-ACQ, October 1987.

[a]Compressed 73-month schedule.

[b]Development start to first flight fully configured missile.

for this project indicated that they felt that assumption to be unrealistic. Both engineers and managers stated the problems of even attempting to produce a stable design during FSD; according to one engineer:

> There was no time to do thoughtful tradeoffs, and little time for even basic design work. The same was true for software. The design was frozen too quickly, and there was too much overlap with production. When the contract schedule was lengthened [N.B., from 40 to 50 months], the additional schedule was all in flight test, and there was still no time for the design effort.

The shortened schedule also required an ambitious and concurrent testing program, with first-flight testing to begin about halfway through FSD. "Any past history said the testing program was unrealistic," according to one manager. "You're lucky to get one shot off a month." Testing problems were exacerbated by the fact that the missile was designed for multiple aircraft and involved three separate test sites.

**THE ROLE OF EXTERNAL DEMANDS**

The most important demand imposed from without the program was the shortened schedule, discussed above. Another external demand, which created substantial problems for both the SPO and

the contractor, was the decision to second source the program.[53] A third was the decision, apparently made within AFSC, to conduct the FSD program with a fixed-price incentive contract. A fourth was the large number of external investigations and audits that occurred throughout the program.

The implications of introducing a second source were far-reaching. According to contractor interviews, the Air Force imposed this requirement as the contractors were preparing their best and final offers on the FSD program. The FSD contract was awarded to Hughes in December 1981, with Raytheon awarded a contract to begin establishing a second source in July 1982. Introducing the second source so early in the program was, presumably, a function of the Air Force assumption that AMRAAM design would be relatively stable by the end of DEM/VAL. The emerging literature on the benefits of second sourcing, which is often critical of the claims of significant savings that result, agrees that "competition has proved an effective management tool in programs in which prototype hardware was evaluated before a commitment to full-scale development."[54] This means that the government reaps technical and performance advantages when contractors compete, but there is little evidence that overall program costs are significantly reduced when competition is extended into production.[55]

Several officials noted that the second-source decision was made on the basis of external pressure. "Lots of people wouldn't

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[53]Note that it was not possible to determine exactly *who* made this decision or whether it originated within the SPO, Systems Command, or OSD. There is no doubt, however, that there was substantial pressure throughout the acquisition community, and in Congress, to use competition as much as possible.

[54]Donald L. Pillig, *Competition in Defense Procurement* (Washington, D.C.: Brookings Institution, 1989), p. 24

[55]Ibid., p. 15. Though there are a few cases of apparently dramatic cost reductions (see Jacques S. Gansler, *Affording Defense* [Boston: MIT Press, 1989], p. 187), such examples often ignore the fact that costs drop as production progresses even in a single-source environment because of learning and that even major reductions will rarely offset the costs of qualifying a second source.

accept programs without a second source, so we had to have competition." Most admitted now that the second source was brought on board far too early, with the issue occupying 50 percent of the Program Manager's time. Raytheon was given the second-source contract early in FSD, well before the missile design was completed. This forced the SPO to deal with two contractors at the same time, amidst problems in missile design, testing, and production processes. Moreover, competition will not save as much money as originally envisioned, in part because full competition was delayed until Lot IV (originally scheduled for Lot III) and because the total quantities have been reduced.

Once second sourcing was initiated, the SPO had the standard problems of getting the contractors to talk to each other. "We got wonderful proposals about what [the contractors] would do, but they tried to get out of it as soon as the contract was awarded." Hughes was reluctant to share its design with Raytheon and "spent as much time fighting transferring stuff as [it has] actually transferring data." The problem was considered so serious that it got to the four-star level several times. HAC objected to the requirement that it, in effect, "teach Raytheon how to build the missile," and those interviewed were unanimous in their criticism of the strategy:

> When it comes to giving information to Raytheon, unless the government puts a gun to our head, we don't give it to them.

> [Second sourcing] was a terrible vehicle: we were giving the other guy, our main competition, our data and our technologies. It was hard for the engineers to accept.

> Relations with Raytheon are congenial at the senior level. At the working level, though, we won't do anything to help them, and don't give them any engineering information; they're already taking our intellectual property. There was no incentive for HAC to make second sourcing work. We thought the contract language was the ceiling of what was required, the Air Force thought it was the floor.

There is little doubt that the second-source strategy introduced additional complexity into the program, not only because the contractors were wary of talking to each other, but also because the missile design was still changing in major ways several years after Raytheon was brought on.

The other major externally imposed requirement was the use of a fixed-price development contract. Apparently, this decision was directed from AFSC (although a review of SPO documents did not uncover direct evidence), and it is clear that in the early 1980s, fixed-price development contracts were fashionable as a way of transferring risk from the government to contractors. The AMRAAM contract had the additional feature of incorporating production options in the development contract.[56]

According to both HAC and some former SPO personnel, the manner in which the FSD contract was managed was inappropriate given the risks inherent in the program. To begin with, there were a number of disagreements over the interpretation of the contract statement of work, particularly over the issue of whether the development missiles had to meet the performance specifications of the production missiles. Second, HAC and the Air Force disagreed over whether HAC had the authority to make design changes. The HAC position, as expressed in interviews, was that in a fixed-price environment, it should have more flexibility to manage its design effort without interference; contract management personnel argued that the issue was the final product, not the specifics of the design. The Air Force, again according to HAC, wanted to retain control over the missile configuration.

A second issue was the nature of the AMRAAM technical specifications. According to early SPO management personnel, the original JSOR, which set out the system peformance requirements,

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[56]There was, according to HAC personnel, at least one confrontation between HAC and government personnel about whether the AMRAAM contract was simply a warmed-over version of the discredited "Total Package Procurement" concept of the 1960s.

was a "wish list" that allowed flexibility to trade off requirements:

> All we were trying to do [in DEM/VAL] was show that the concept would work. About the time it went into FSD, when the JSOR group met and came up with the draft, it was a wish list, not a firm requirement at all. . . . We told the contractors that nothing in there was sacred. . . . The early AMRAAM thinking was 'here is the JSOR: Come as close as you can, but if there is a requirement that will affect cost or pull this thing out of line, let's talk about it."

This official continued, "I think what happened is that between Raytheon and HAC, that somehow they made that JSOR a firm requirement. To me that was a super mistake. . . . The cost growth came when [the Air Force] left the original intent to use the JSOR as a guide and made a real requirement out of it."

By 1985, SPO autonomy was curtailed as both OSD and Congress became actively involved in the program. SPO and contractor personnel saw two major problems with the heightened degree of oversight. First, it increased the number of demands placed on the program that SPO personnel saw as interfering with their ability to manage the program: "We've had more oversight from external organizations than any other program not involved in illegal activities." Some personnel saw these oversight efforts as indirect attempts to curtail or kill the program, especially by members of Congress: "There were lots of demands by external authorities from people who wanted to slow roll the program." Others noted the extensive testing, arguing that AMRAAM is the most tested missile program ever, and that the SPO is being required to demonstrate things that no other program has had to do.

A final external requirement has been the demands of the large number of investigative visits to the AMRAAM SPO. AMRAAM has been investigated and audited more than 100 times since inception, with an increase in the number of studies since 1986 (see Table 3.3). From the beginning, the program manager's time

Table 3.3

Investigative Visits to AMRAAM SPO

| 1981[a] | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 10 | 9 | 8 | 7 | 14 | 12 | 11 | 5 | 16 | 102 |

NOTE: Includes USAF and OSD audit and Inspector General offices, General Accounting Office, and miscellaneous visits.

SOURCE: SPO figures, as of 3 December 1990.

[a]Includes only part of year.

has been taken up by "Washington kind of issues instead of managing the program." Program control people stated that the audits take up a great deal of personnel time and can bring the entire program office to a halt.

The demands placed on the program by external actors have proved troublesome, according to SPO personnel, because they often reflect little understanding of the program's management needs. The testing personnel in particular objected to the external demands and noted that some of the testing requirements (imposed by both Congress and OSD) are often contradictory or even physically impossible. They gave two examples (though these were not documented): (1) Congress wants the program to demonstrate the ten-year shelf life of the missile as a condition of full-rate production. Mature production missiles are at most a few years old, so the testing people considered this requirement impossible to meet. (2) Other requirements ask the missile to be tested in environments that are considered unsafe for range safety reasons. "Last year the program was held up because the GAO said 'you haven't done all your testing.' They've done so much more testing than was originally in the TEMP,[57] it's pitiful."

Although there are few comprehensive data on investigative visits to acquisition programs as a whole, AMRAAM's experience was exceptional in comparison with other programs in RAND's study of risk in weapon system management. This is particularly true of the programs that achieved the most successful outcomes; in those

[57]Testing and Evaluation Master Plan.

cases, an experienced SPO retained a high degree of flexibility and the programs were not as visible to higher authorities.[58]

A related issue is that attention is so intense that any action the SPO takes is often criticized, for what officials there see as unfair reasons. SPO testers argued that often it is the aircraft software that is at fault for missile problems and failures--often because the aircraft software is not able to handle certain AMRAAM mission profiles. Yet when the SPO "fixes" the aircraft software to allow the mission, it is accused of "tailoring the shot" to enhance the chances for success.

Program personnel are clearly in a difficult position, because external oversight has become "hypervigilant," and even minor problems lead to calls to cancel the program. Moreover, attempts by OSD to satisfy congressional critics have, in the opinion of one official, led to problems: "There were a few congressmen who saw this as an expensive program, and then you get DoD in a responsive mode. They overresponded and tried to make it a perfect missile."

The SPO also feels that external authorities are springing surprises on the program. The Office of Test and Evaluation in Washington notified the SPO two days before a critical meeting of the Conventional Systems Committee (Defense Acquisition Board) that they would not certify the missile, claiming that testing had been inadequate.

**MANAGING EXPECTATIONS**

Much of the external attention (especially in Congress) is the result of the program's performance shortfall when compared with the initial estimates. A program that experiences 200 percent growth in unit costs is bound to attract a great deal of

[58] F. Camm, *The Development of the F100-PW-220 and F110-GE-100 Engines: A Case Study of Risk Assessment and Risk Management*, RAND, N-3618-AF, forthcoming; F. Camm, *The F-16 Multinational Staged Improvement Program: A Case Study of Risk Assessment and Risk Management*, RAND, N-3619-AF, forthcoming; T. Webb, *Risk Management During the Development of the Global Positioning System Block I Satellite*, RAND, N-3621-AF, forthcoming.

attention (the Congressional Budget Office study of the Phoenix, and Sidewinder and Sparrow upgrades, noted that unit cost growth in those programs averaged about 43 percent). By the 1985 APREP, when it became clear that the program would slip by at least 2-3 years, Congress became increasingly critical. It is not hard to surmise that management becomes tough when a program faces cancellation virtually every year. The result is management by fire drill, which interferes with the normal process of identifying problems during development. It also raises the possibility that midlevel managers will be reluctant to send problems up the chain of command.

Of the early program estimates, the least accurate was AMRAAM cost. Unit costs rose steadily throughout the history of the program, largely because the program office made extremely optimistic estimates in the early phases of the program.

The initial, and unofficial, unit cost estimates were $40-50,000 in 1978 dollars (made in 1977).[59] A 1978 program office study estimated a unit cost of $67,000 (1978 dollars). By 1985, the program office estimate was $208,000 (1978 dollars), more than triple the original official estimate (these estimates did not count any savings from competition or APREP).[60] This cost growth was a major driver of the 1985 OSD review and the resulting APREP program (see Table 3.4).

Table 3.4

Chronology of AMRAAM Cost Estimates (20,000 units, single-source, prior to APREP unit price)(thousands FY85 dollars)

| 1978 | 1980 | 1982 | 1985 |
|---|---|---|---|
| $67.5 | $95.4 | $138.2 | $208.3 |

SOURCE: Joseph Large et al., *Cost Estimates and Estimating Procedures in the IIR Maverick and AMRAAM Programs*, RAND, R-3584-AF, May 1988, p. 34.

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[59]Boykin briefing to Senate Armed Services Committee, *FY 78 Authorization for Military Procurement, Research and Development, and Active Duty, Selected Reserves, and Civilian Personnel Strengths*, Part 6 (Tactical Air), p. 4624.

[60]See Large et al., p. 34.

Two important factors in cost growth were design uncertainty and advocacy. The original estimates were derived at a time when the SPO had little idea of what the final product would look like. In 1978, five contractors were working on different designs, with different technical approaches, and the technologies were far from mature. "At Milestone I, no firm design had been chosen. Cost analysts based their estimates on a generic design that included features of all five candidate missiles."[61]

Moreover, AMRAAM faced stiff competition for start-up funding from the AIM-7M. The SPO originally promised significantly better performance at lower costs; cost estimates were set low "because otherwise the program would never have gotten off the ground. . . . We knew that the missile would cost more." In a comment on a 1987 GAO report, DoD admitted that early optimism "could have played a role" in cost growth but noted that this was a generic problem common to many acquisition programs.[62]

The shift in how the JSOR was interpreted between DEM/VAL and FSD also played a role in the expectations problem. An official who worked on the original JSOR indicated that "there were a lot of numbers drawn out of the air. We saw that the Sparrow did this, so let's make [AMRAAM] twice as good. A lot of numbers were in there because they looked good." The problem is that once the shift is made from a "wish list" to a firm requirement, virtually everyone is likely to forget that the early program requirements were not promises but guidelines. This same official continued with an example:

> The JSOR said that you don't want a missile that limits the aircraft: if you have an F-15 with a radar range of so far, you don't want to wait to shoot the missile. But when the Air Force put the specs in, it still says the missile cannot limit the aircraft in any way, so it was interpreted that if the aircraft is pulling 9 Gs you still have to launch. That's not what we intended, and you shouldn't have to meet that requirement. If you're in a dogfight, you've wasted your opportunity to use

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[61]Large et al., p. 35.
[62]GAO, *AMRAAM Cost Growth and Schedule Delays*, p. 30.

> AMRAAM, and you have cheaper missiles that can do the job.

One reason for this shift was that both Raytheon and Hughes expressed confidence during the FSD proposal phase that they could meet all of the requirements for the missile; HAC knew that the government intended to put the contractors in a position where they would have to bid aggressively but went along because it was afraid of jeopardizing its competitive position:

> We knew the government wanted to use DEM/VAL and the FSD competition to cause aggressive bidding to detailed specifications, which would be baselined at contract award. This would give the Air Force technical control over the product at a sufficient level so that they could guarantee performance, and would use competition to drive contractors to bid aggressively, and use a fixed-price contract to cap government's cost. . . . We were torn between how hard you push, and your competitive position. You couldn't torpedo your chances.

**SPO EXPERIENCE AND MANAGEMENT STABILITY**

Some observers of the AMRAAM program identified SPO management inexperience as one possible source of the program's difficulties. The Air Force did not have much experience building air-to-air missiles when it started the AMRAAM program. Both the AIM-9 and AIM-7 programs were joint programs housed in the Navy; the last pure Air Force air-to-air tactical system was the Falcon missile, a first-generation semiactive radar missile built in the 1950s by Hughes. While the Navy liaison in the SPO spoke of Navy enthusiasm about the missile, there are references in the trade press to the Navy's lack of confidence in Air Force management of air-to-air programs and, in particular, the SPO's location at Eglin Air Force Base, which was considered more of a test facility than an acquisition center.[63] One HAC source indicated that Eglin

[63] "Navy officials who reviewed the AMRAAM program [in 1984] were critical of many aspects of it, including the fact that the program office is locted at Eglin AFB, Fla. They consider Eglin to be a test facility lacking the management experience necessary for a program with the complexity of the AMRAAM." Robert

was accustomed to procuring equipment for its testing programs: "People were used to the concept of having a large pool of contractors, compete them on the basis of cost, and then pick the winner." While it is difficult to determine what impact this had on the program, both HAC and some SPO personnel portrayed contractor-government relations during FSD as confrontational; this was, according to contractor personnel, exacerbated by the fixed-price contract:

> What made it unbearable was the combination of using competition to drive ambitious performance, making firm requirements, and coupling that with a fixed-price contract, with the government having no need to control costs or make tradeoffs. Under a cost-based contract, we could have gone back and said, "here's something that's really hard to achieve," and the government would have some responsibility in that area to make a decision about whether it was worth it. With a fixed-price contract, the government had no responsibility to do that. Cost was not their concern.

This may be slightly exaggerated, as it is possible to modify fixed-price contracts to change the statement of work or cost figures (as in the engine programs; see Camm, fn 2). Nevertheless, these modification decisions do not take place in a vacuum and are surely harder to implement once a program is in trouble. In 1984, according to one Hughes source, the company almost succeeded in getting the contract modified but failed "because it would have looked like a bailout."

The AMRAAM SPO has had seven program managers since 1976; while the GAO is critical of the rapid turnover (especially in the early 1980s), SPO sources note that two of the managers with the shortest tenure were strictly interim appointments who served

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Ropelewski, "Pentagon Considers AMRAAM Cancellation," *Aviation Week & Space Technology*, January 28, 1985, p. 20. AMRAAM's joint status, and the coordination problems that such programs often entail, was not a major factor in the program's difficulties; in any case, such problems, if they did exist, were dwarfed by other issues. It is reasonable to surmise, however, that the Navy's early lack of enthusiasm probably hindered AMRAAM's ability to defend itself in Congress.

while the Air Force looked for a permanent replacement. However, it is clear that during critical points in the missile program there was little continuity in the PM position. Between June 1980 and June 1984, the program had three managers who served an average of 16 months each. Since 1984, there have been only three program managerss: Major General Thomas Ferguson served for four years, from July 1984 to June 1988; Brigadier General Charles Franklin, who served until August 1991; and the current program manager, Harry Schulte (a civilian). All SPO personnel with whom I raised the issue of management expressed great confidence in Franklin; in particular, they stress his efforts to get the attention of the aircraft SPOs to work the AMRAAM integration issue.[64]

[64]Many SPO personnel spoke of the difficulty of integrating AMRAAM software with the various aircraft systems and of the effects of even minor software problems on missile performance. In one 4-on-4 test (probably in August 1989), for example, all four missiles failed to hit their targets; three of the missiles failed because the *aircraft* radar was picking up false targets. The fourth missile failed because of a minor software problem that required only a few lines of code to change (apparently a constant that the missile computer used to make some calculations was wrong).

## 4. CONCLUSION

It is easy to find villains in the AMRAAM story: the highly compressed schedule, the use of a fixed-price contract for a technically ambitious and risky program, and apparent management inflexibility by the government in its attempt to hold Hughes to the original FSD contract. Yet if we move to the broader issues, what appears to have been the major factor in AMRAAM's troubled history--given that the system *does* work--was that it was forced to comply with a large number of demands imposed from external actors. From this starting point, we can draw the following observations about risk and the interpretation of risks:

- Weapons system development programs often have to answer to a broad range of constituencies, within the services, OSD, or even Congress. This observation is usually made in the later stages of programs, when external actors begin to make demands in response to perceived technical or management problems; however, the same sort of dynamic can occur when individuals and institutions are making the initial decisions about how a program should be structured. In AMRAAM's case, basic decisions about acquisition strategy--in particular, the development timetable and establishing a second source--were made (or imposed) because of the need to satisfy demands *external* to the program, not because of what the program, narrowly defined, required.

- Formal structures and procedures designed to reduce uncertainty cannot be relied upon to counter optimistic estimates of performance, schedule, or cost; in some cases, they may even encourage them. The emphasis on competition in the early phase of the program, when combined with the A-109 directives that encouraged giving

contractors maximum design flexibility, meant that early cost and schedule estimates were derived at a time of great uncertainty about what the final design would be. The formal risk assessment the Air Force did in the late 1970s did identify the areas of risk (guidance and control, aircraft integration), but it does not appear to have had much success in helping the Air Force to *manage* that risk.

- *Expectations are relative.* Initial program estimates form a baseline against which eventual performance will be judged. Overselling the program at the beginning, then, can lead to serious difficulties later on as technical problems--inevitably encountered in development--make system performance and management look poor in relation to the perfection originally promised. The general tendency to oversell at the beginning is well known, and in AMRAAM's case may have been exacerbated by direct competition with an upgraded Sparrow (AIM-7M). On AMRAAM, the Air Force grossly underestimated the missiles' cost (the early unit estimates were $40-50,000 in 1978 dollars; the final cost will probably be at least 4 to 6 times greater) and the degree of technical difficulty that developers would encounter. Cost increases, schedule slips, and technical snags were all factors in increasing external oversight (particularly in Congress), which consumed more and more of the SPO's time.

- External oversight *can* be counterproductive, as it raises the likelihood that the system must respond to forces having little to do with performance or management. In AMRAAM, congressional and OSD pressure to shorten the acquisition cycle and maximize competition was an important factor in how the Air Force structured the

program--the result was a schedule and competition plan that was not consistent with the degree of risk involved in the program.

- Concurrent development programs are simply inappropriate for technically risky programs. The technical requirements in the AMRAAM program were simply beyond the ability of either the contractor or the SPO to solve in the allotted schedule; warning signs appeared as early as the end of DEM/VAL, yet the Air Force commitment to the earliest possible IOC meant that the adjustments to the schedule were inadequate. IOC was achieved five to six years after the original September 1985 estimate. The chief engineer on the program indicated that the program risk was manageable under the original 90-month schedule but that the compression drove risk to unacceptably high levels.

- Fixed-price contracts do not work in technically risky development programs. This is already recognized, and the government has backed away from using fixed-price contracts during development. Apart from often placing too much financial risk on the contractor, fixed-price contracts in the AMRAAM program interfered with the need to make tradeoffs between cost and performance. AMRAAM specifications were established before either the government or the contractor had enough information to determine what was realistic to expect from the missile. Yet once the contract was signed, the government "held Hughes' feet to the fire," causing, in the opinions of some SPO and contractor sources, undue contentiousness, management problems, and cost and schedule slips.